Title: Method for controlling the program of a washing machine and washing machine using such method.

The present invention relates to a method of controlling the program of a washing machine comprising the recording of the quantity of water supplied to the tub of the washing machine.

Such a method is disclosed in GB 2070648, which is based on the knowledge that in a water level controlled program cycle of a washing machine the quantity of water supplied constitutes a measure of the absorbability of the washing and, with the same type of washing, also a measure for the weight of the washing. Such known method cannot give optimal results since the number of refilling operations for keeping the water level around a nominal level of water in the tub makes such method very time consuming.

The method according to the present invention does overcome the above technical problems and guaranties a minimum 'performance water level and safety control. According to such new method, the load detection and the time in which water (according to the detected load) is fed in the drum is very quick if compared to the known methods.

The features reported in the appended claims characterize the method according to the invention. Preferably the method makes use of a continuous water pressure sensor that enables a better control of overflow and leakage, thanks to the continuous level monitoring and "trend" analysis in addition to the level measurement. Moreover such kind of sensor allows a better foam detection, improves spinning_performances by avoiding water ring formation and detects foam before and during the distribution.

The main idea underlying the present invention for estimating the load quantity is to monitor the water difference between the filled water and the "free water" in order to obtain the water that is absorbed by the load. With the term "free water" we mean the amount of water which is not absorbed by the laundry and which is contained in the washer tub. From the absorbed water the laundry load can be estimated. The assessment of free water is not used by known methods, since they are all focused only on the amount of water supplied to the tub for keeping water level around a nominal value. With these known methods it is not necessary to use a continuous water level sensor. If we call "absorbed water" the water quantity located within the load, and assuming that the free water can be determined by measuring the water level by a pressure sensor, the following mathematical relation deduces the absorbed water:

liter in – free water = A_w

provides the water quantity absorbed by the load itself.

In order to get information on the above-mentioned specific absorption (SA), the applicant has carried out tests done with a fixed amount of laundry and different water amounts. The water level value has been considered after a certain time of agitation, and the water absorbed has been computed by using the mentioned method. By dividing the water absorbed by the load quantity, the specific absorption SA (water absorbed/kg load) has been determined.

Thanks to the above tests, the applicant discovered that in the range of the water used, the higher is the water amount supplied to the tub, the higher is the absorbed water and the free water. In other words, the applicant discovered that the specific absorption SA is water filled dependent or, in another way, the specific absorption SA is free water dependent. This fact has important consequences in term of finding the best way for controlling the program of a washing machine. With a fixed amount of laundry, the applicant has prepared a diagram (and related computerized algorithm) that links the specific absorption SA to the water supplied to the tub and to the free water.

The applicant has also discovered that the specific absorption SA is load dependent, i.e. the absorbency of 7kg load is different from the absorbency of 1 kg load. The main cause for this fact is the dependency on the volume ratio VR, where VR = Load Occupied Volume /Total Drum Volume: the higher is the VR the lower the A_w (and SA consequently). In first approximation specific absorption *SA* has to be linked to the absorbed water A_w. According to the average values of tests carried out by the applicant with a commercial washing machine, the SA is 2.0 (7 kg load) in correspondence of 14 litres absorbed obtained by filling a total water amount of 19 litres. The SA becomes 2.75 in case of 1kg load that absorbs 2 litres vs. 7 litres filled in the machine. A simple line can been drawn between these two points for inter-medium loads (see attached figure 2). This "curve" can be also a straight line (as in figure 2), and this depends mainly on the volume of the drum and of the pressure sensor position.

As the absorbed water is still a function of the total amount of water supplied to the tub and of the water level, the specific absorption SA can be represented in a 3D format, easily transformed in electronic form. The chart

shown in figure 3 is the cotton characteristic absorption for the specific washing machine used in the tests.

The present invention will be described further, by way of example, with reference to the load sensor algorithm used for controlling the washing machine and with reference to the attached drawings, in which:

- Figure 1 is a simplified view of a drum washing machine according to the invention,
- Figure 2 is a diagram showing the specific absorption vs. adsorbed water, such diagram being used in the method according to the invention,
- Figure 3 is a 3D diagram showing the cotton characteristic absorption for the specific washing machine used by the applicant in the experimental tests,
- Figure 4 is a chart showing the liters of water to be used for load "equivalents",
- Figure 5 is a diagram showing how the water level in the drum changes with time,
- Figure 6 is a block diagram showing how the machine according to the invention can check a pressure sensor failure,
- Figure 7 is a block diagram showing how the method according to the invention can check the total water amount loaded in the tub,
- Figure 8 is a block diagram showing how the method according to the invention can check whether the pressure sensor is working properly,
- Figure 9 shows a diagram of water level and total water vs. time, such diagram being used for detecting a possible water leakage,
- Figure 10 is a flowchart showing how the determination of a "steady state" is carried out with the purpose of detecting a water leakage,
- Figure 11 is a diagram showing the pressure measured by the pressure sensor and drum speed vs. time, and
- Figure 12 is a diagram showing how the drum speed is changed by the control from the default A, t, B curve to the A', t', B' due a certain amount of detected water.

In a washing machine according to the invention, a flow meter 10 in the water supply line and a continuous water level sensor 12 are used, so that two information can be directly measured and one can be deduced, i.e.:

- total supplied water [liters]
- water amount in the tub "free water"[from mm to liters experimental curve]
- water amount in the load ("absorbed water") as the difference between total supplied water and free water .

Both flow meter 10 and level sensor 12 are connected to a central processor unit 13 of the program control system. The "absorbed water" depends on the load quantity and the specific absorption SA.

The specific absorption is a function of the total amount of water supplied to the tub and the free water.

Load Equivalent = (Tot Litres-Free Water) / Specific Absorption

Free Water = f (Water Level)

Specific Absorption = f (Tot Litres, Water Level)

The load quantity can be computed starting from values measured by the flow meter 10 (water supplied to the tub) and from the continuous water level sensor 12. From such value and from the experimental curve/equation that links the water level with the free water, it is possible to determine this latter. From the values of total amount of supplied water and from free water it is determined the absorbed water. From the diagram/equation of figure 2, a first value of specific absorption SA* is determined, based on the absorbed water. Then, from diagram/correlation of figure 3, a second value of specific absorption SA is determined, i.e. the specific absorption of the standard cotton for a specific washing machine. This value is a function of SA*, the total amount of water supplied to the tub, and the water level in the tub. At the end the cotton load equivalent is determined as ratio between water absorbed and specific absorption SA.

The above algorithm is applied continuously in the main loop software control of the washing machine. The main benefit of such continuous implementation is that when the load information is obtained, one can also set the desired water quantity to use. In order to know the correct water quantity to be used for an estimated load equivalent, the applicant has designed a chart (figure 4) showing the liters to be used for load equivalents. Obviously also this chart as all the other mentioned in this description can be "translated" in electronic format and embedded in the software controlling the program of the washing machine.

Once the load quantity is estimated, the water quantity to be filled can be controlled according to the above "Liter to use" chart.

An inlet water valve 14 has to be controlled for satisfying the water needs. In order to speed up the control of the water absorption of the load, i.e. the preliminary phase in which the water is supplied to the tub T and during which both the water supplied and the water level are monitored in order to get an estimate of laundry load, it is preferred to calculate the derivative of the water level in order to predict the future water level, i.e. without waiting for an actual reaching of such level. This preferred method consists of computing the load quantity on the basis of a water level prediction. This embodiment is schematically shown in figure 5.

In such figure, the water level behavior is represented. During a filling phase, at t_j instant, the derivative function provides an estimation of the level at the next interval time. If this value is known in advance, one can decide to stop the water filling due to extra water consumption estimation. During the next period the water starts to be absorbed by the load and the water level decreases. In this phase the derivative function, computed at the t_k time, might force the load detection algorithm to estimate a bigger load. If so, an additional re-filling will be enabled and the water is provided in advance compared to the usual control. This embodiment of the control method according to the invention, is based on the following equations:

$$\mathrm{Pr}\,edictiveLevel = WaterLevel + K_p * \frac{\partial WaterLevel}{\partial t}$$

$$FreeWater = f(\mathrm{Pr}\,edictiveLevel)$$

$$SpecificAbsorption = f(TotalLiters, \mathrm{Pr}\,edictiveLevel)$$

$$LoadEquivalent = \frac{TotalLiters - FreeWater}{SpecificAbsorption}$$

Where, according to experimental tests:

Kp=1 if derivative is < -1.5mm/32sec. (used to accelerate filling)

Kp=0.25 if derivative is >0.25 mm/32sec. (used to avoid overshoot)

and 32" is the derivative time.

The test carried out by the applicant with a method according to the invention have shown a very good correlation between the actual laundry load and the

actual total amount of water supplied to the tub T as a preferred value for such laundry load.

The total filling completion time varies, for the 7kg load, from 250 sec to 450 seconds. The final load quantity parameter, used for controlling the program i.e. rhythm, washing speed, washing duration, unbalance detection, inertia detection, rinse number, water to be use in rinses, spinning speed, ect. has been detected after a reasonable time in which the water level is almost steady.

According to a further feature of the present invention, it is provided a method for checking a possible failure of the pressure sensor by means of a check of the pressure value. In case the pressure information is not in the predetermined rage, established by the sensor supplier, a failure message is provided to the central processor unit 13 of the washing machine. Figure 6 represents an example of the pressure sensor failure check. The expected rage value of the sensor, that provides a voltage output Vp signal, is for instance from 0.5 Volt to 3.5 Volt. In case the sampled value is above 3.5V, it is expected to have the sensor "open", in case it is below 0.5V, "short circuit" condition is expected. It will be "in range" if none of the said conditions are detected. "Sensor State" represents a variable to which the sensor condition is assigned. The "P=Water Pressure" variable is obtained by converting the signal read by the pressure sensor (in this example voltage) in pressure, indicating the millimeter of water column. Ks and Os represent the Gain and the Offset values given by the sensor supplier.

Once the signal, coming from the pressure sensor, is considered to be in the admissible range, an additional check, regarding the total filled water amount, is here proposed. The main purpose of the present safety control, shown in Figure 7, is to switch off the valve and stopping the water flowing in case an abnormal water quantity is filled in or in case the valve is opened for a long time. The detected failure will then be processed up to inform the user that a water leakage is occurred or the valve is blocked in its open condition.

In the block diagram a check of the valve state is carried out: open or close is done. In case the valve is open, a variable "TimeOV" is incremented so that its value indicates the incremental valve opening time. MaxTimeOV represents a time limit, determined by the control design; in case TimeOV exceeds the time limit, a failure indication will be generated. TimeOV is set to zero in case the valve is close meaning that the load detection algorithm has established that the

right filled water quantity is provided to the estimated load quantity. In the block diagram the check of the total water filled in is also included. The total amount of water filled: "Liter IN", data provided by the flow meter, is always processed and in case exceeds a predetermined value MaxLiterIN a failure indication will be generated.

Another safety control system according to the invention has the purpose of evaluating whether the pressure sensor is working properly, i.e. if the sensor is "alive" or "dead". It may happen that the sensor is blocked to a fixed and "in range" value. The way to distinguish the two conditions is to evaluate the acquired measures, done for a certain period, and verify if pressure variations are detected while the tumbling occurs.

The block diagram of Figure 8 shows that every time the control is executed, a counter is incrementing its value in case the Sensor State is "in Range". Every certain number of pressure sensor readings, in the example 160, the evaluation of the acquired date is done. The "Sum Variation" variable includes the sum of 160 values; each value represents the "Delta Pressure" value (difference between actual P2=P and previous P1 measure, positive and negative variations are considered all positives). It is in fact expected that during the washing or rinsing phases, in which the drum is tumbling, the water level varies due to the elevators and the load movement. This small variation is accumulated (i.e.160 values) to have this data more consistent. The "Sum Variation" is then processed and compared to a predetermined value "AliveValue". In case "Sum Variation" is considered too small, a failure of the pressure sensor is detected and an alarm signal is provided to the user.

In case of water leakage the control has to alert the user and/or suddenly pump out the water to prevent home flooding. A water leakage detection control according to the invention is here disclosed and it is based on a comparison between water levels acquired in different times.

The chart of Figure 9 shows an example of water pressure behavior and its filtering signal during a washing cycle. In the first phase there is the water fillings according to the load detection algorithm. The total water filled is also plotted. The filling is concluded after a certain time (about 250 seconds) and small load absorption is then observed by the decreasing of the water level. We can consider a stable condition after a reasonable time i.e. 100-200 seconds starting

from the last filling completion. The measured Water level in steady state condition is so stored in memory as a reference value: WLRV.
With the purpose of verify cases of water leakage, periodically water trends evaluation and comparison values between the actual water level and the WLRV are computed.
In the flow chart of Figure 10 the determination of the Steady State condition is done by comparing the execution of the last refilling time with the washing /rinsing execution time. If for instance 200 seconds are elapsed, the steady state condition is set to TRUE. The Actual pressure level P is then assigned to the WLRV variable and three pressure values measure at different times: present (P3=P), past P2 and P1 are updated. Water Leakage condition is then detected if abnormal water absorption is detected (WLRV > DPMAX), where DPMAX is considered as maximum water pressure change, or when the water slope DP is considered to be abnormal during the washing/rinsing phases. The water slope detection is a very important feature enabling the detection of small water leakage that are in general very difficult to monitor. The consumer benefit of the proposed control, compared to the ones provided by traditional mechanical pressure switches, is that a failure is detected before the minimum level (i.e. 20mm) is reached. As a consequence less water will be flooded.

According to a further feature of the present invention, a new method is disclosed for reducing the system tolerances due to pressure sensor, tub tilting (in case of washing machine with tilted drum) and unlevelled floor.
The "level calibration function" can be activated by the user or by service during the installation of the washing machine, by pushing a special button or buttons combination. The calibration consists, with motor OFF, in filling a known water amount (i.e. 3.5 litres), measuring the corresponding water level (P_nw) and saving in EEPROM the (P_offset): difference between (P_ref) and the (P_nw):
P_offset= P_ref - P_nw
The obtained offset value will be used to compensate the level measure for the free water amount determination. P_ref is a specific parameter of the free water curve, detected and stored as a default value, obtained in ideal condition when the reference water amount (i.e.3.5 liters) is filled in.

According to a further feature of the invention, a control is used which is particularly useful for washing machine having big load capacity. In the very early

spinning phase, even if the drain function is activated, the pump P (figure 1) might be unable to drain in time the water extracted by the wet load. Without a special water level control, it might be possible to start spinning with a consistent water quantity inside the drum. The primary effect is that the remaining water can not be expelled and will turn with the same speed of the drum (water ring effect). A second effect is the increase of the motor friction due to the water ring effect and, in certain cases, especially for the first two spinnings in which the amount of detergent is still high, the friction might be so high to block the motor.
The present control system has the objective to monitor the water quantity during all the spinning cycle and adapt the spinning profile accordingly.
The referred figure 11 shows a case in which a spinning speed is performed between two rinses with a moderate load quantity. At the end of the first rinse, the pump is activated and the water level is decreasing very fast. Generally the pumping is activated during all the spinning phase. After the distribution phase the spinning starts and a big amount of water is extracted from the load. As it is visible, a certain amount of water is still present while the spinning is in progress. After a certain time the water extraction can be considered concluded but, in the drum, some water is still present because was not pumped out. The water level, indicated in the chart, has to be considered as the sum of two pressure effects: pressure due to the actual water inside plus the pressure produced by the fast rotation of the drum and the consequence formation of wind on the drum wall. The estimation of the pressure due to the "wind" effect has to be carefully determinate to avoid wrong control decision. In case of big load quantity the amount of water extracted during the distribution phase and in the first spinning phase will be higher while the extracted water has a limited flow (unless more expensive pump is used). The consequence risk of spinning with high water quantity will be very high. The control proposal according to the present invention is so based on managing the spinning speed profile based on the water level. Figure 12 describes the possible solution of the control algorithm that modify the theoretical spinning profile A slope, t plateau time and B slope according to the water pressure detected during each phase. The A' slope is performed in case higher water level is detected, t' is a longer waiting time allowing a longer water extraction from the drum, B' is also shown with an lower slope as an example of multiple areas in which the spinning vs. water level can be applied. The slopes

and pause time are clearly dependent from the detected water level and in general the higher is the water level the lower will be the speed slope and the higher will be the pause time.